RE-COMMISSIONING OF A VAV AIR-DISTRIBUTION SYSTEM

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SUMMARY

Three years after its start up, the building considered here is not yet providing a satisfactory comfort to its occupants. Too cold and too hot environmental conditions were too often encountered in different occupied zones, mainly in mid-season and in summertime.

The execution of a re- commissioning process would support in resolving these problems.

Previous verifications allowed us to confirm that almost all HVAC components considered are technically “correct” and that almost all problems are coming from mistakes committed when installing and tuning these components.

The re-commissioning presented in this paper is based on both calculation and experimental data.

INTRODUCTION

The system considered includes the VAV boxes, the air distribution network and the air handling units. The fundamental purpose of this re-commissioning is to answer two questions :

1) Are the occupied zones receiving enough fresh air ?

2) Are the VAV boxes able to vary the air flow rate in a domain which is large enough to guarantee a satisfactory control of the inside environmental temperature ?

THE PROBLEM

Three years after its start up, the building considered was not yet providing a satisfactory comfort to its occupants. Too cold and too hot environmental conditions were too often encountered (even at same time) in different occupied zones, mainly in mid-season and in summertime. Some of the VAV boxes produced in some cases, too much noisy.

It’s obvious that a second commissioning process would support in resolving these problems. It’s also obvious that when receiving too many complains, the manager could not always find the best solution and that too many “alterations” can not made inside the whole control and management system…

DESIGN AND MANAGEMENT

Commissioning objectives can be situated at different levels:

- Verification of how well the building and more specifically the HVAC plant is operating, compared to the previous specifications;
- Verification of how well the system was installed, compared to the state-of-the-art practice;
- Verification of how well the system was designed, compared to the design intent.

Focus is given here to the two first levels: the plant “perfectly installed”, according to the specifications is taken as reference.

Two design “limits” have to be mentioned, with the VAV system considered :

1) Even if the fresh air flow rate is sufficient in average for all the zone supplied by a same air handling unit, some zones may receive too little and some other ones too much.
2) Even if the VAV boxes are able to vary the air flow rate, according to the design, this doesn’t guarantee a satisfactory control of the thermal environment inside all occupancy zones in all occupancy and weather conditions. We also know that, if the maximal air flow rate is high enough for highest thermal loads, the lowest air flow rate might be too high in mid season, when the heating system is not used.

In mid season and/or in partial occupancy time, it may occur that the VAV system is no more able to cool enough some heavily loaded zones, without cooling too much some other ones (less loaded).
If, after having tuned in the best way all the parameters of the VAV system, such problem is still occurring, the only solution is to use also the heating system (even outside the normal “heating” season).

MAIN RESULTS GOT FROM PREVIOUS RE-COMMISSIONING STEPS

In short, we may say that previous verifications allowed us to confirm that almost all HVAC components considered are technically “correct” and that almost all problems are coming from mistakes committed when installing and tuning these components.

It was found, among others, that :

- Most of the thermostats of the VAV boxes were not correctly connected or tuned;
- The supply air pressure was not correctly controlled (because of many alterations in the system : pressure signal conversion, set point, frequency range, etc);
- The supply air temperature was poorly controlled (due to a wrong definition of the outside air temperatures);
- The fresh air flow rate was also poorly controlled.

It was also verified that the VAV boxes, the fans, the cooling coils, the pumps, the chillers and also the control system could “give” almost what was expected from them.

MODELING OF THE AIR DISTRIBUTION SYSTEM

In first approximation, all the VAV boxes are supposed here able to “impose” their own airflow rates. This is only true if they are correctly mounted, if their thermostats are well tuned and if the supply pressure stays within an acceptable range.
The same first approximation can be applied to the fresh air control (Figure 1).

But, if one of these subsystems is submitted to an inappropriate pressure, it looses its “controllability”:
- When supplied with a too low pressure, the behaviour of a VAV box is unpredictable.
- The fresh air system can be out of control, because the pressure behind the mixing box is not low enough. If the fresh air damper is already fully open, the only solution would be to close a little more the recycling air damper, but this would increase the pressure difference imposed to the fan.

Hopefully, not all the resistances have to be experimentally identified: some initial guesses are available:
Head loss calculations are performed by the consulting engineers as well as by the HVAC installers. The first step is to retrieve that information and to try to understand what are the underlying hypotheses. This helps in determining the “reference performance” of the building.
In parallel, the network can be re-calculated, using state-of-the-art models.

The model used in this case includes both the AHU (Figure 1) and the network (Figure 2).

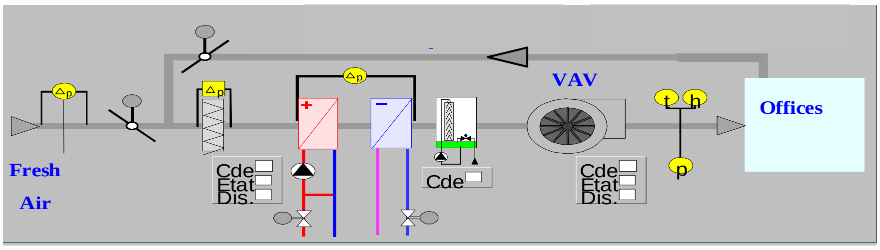

Figure 1: Air handling unit

The whole air network can be simplified, in such a way to make only appear a limited number of offices supplied by the same AHU. The model of the network is taking into account the main pressure drops appearing in the ducts and accessories.

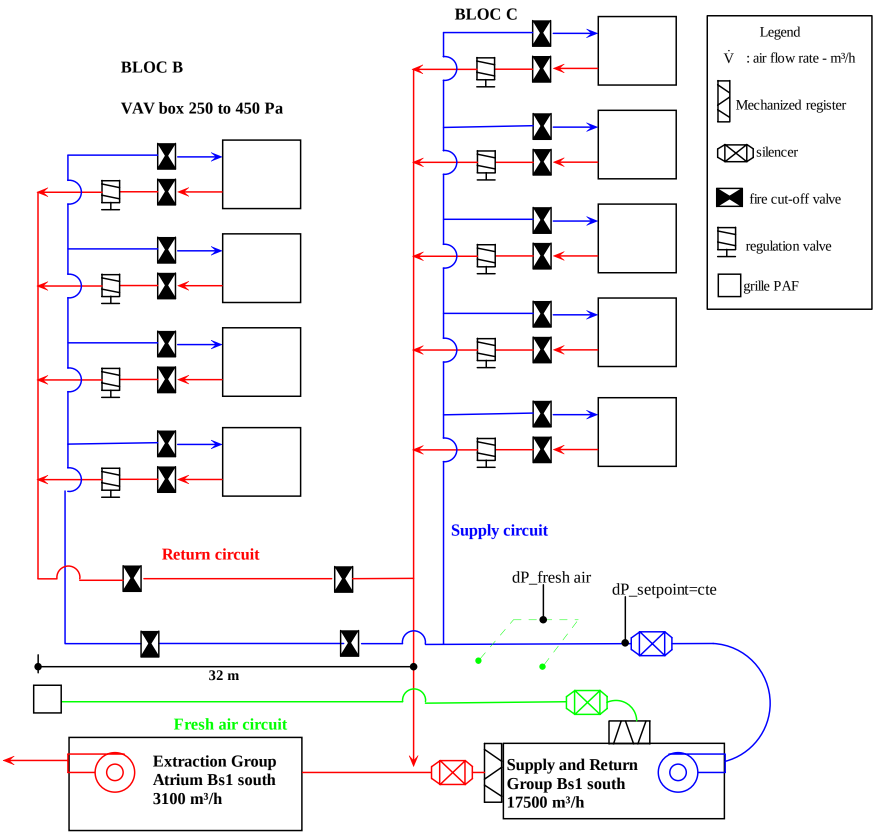

Figure 2: AHU and its network distribution

USE OF INFORMATION CONTAINED IN THE AS-BUILT FILES

The network can be analysed on the basis of the data available in the "as-built" document. This analysis proceeds in 3 steps:

- Calculation of the total pressure distribution using available technical data and sizing calculations, in order to satisfy the most disadvantaged rooms;
- Comparative analysis of those results with that of the HVAC installer;
- Analysis of the results of the TAB operation.

In our example, each AHU is connected to two blocks , each block includes several levels (eg 4) , each level is divided in two zones by a central corridor. Each zone includes different offices, with one or two VAV boxes for each office.

CALCULATION OF TOTAL PRESSURE DISTRIBUTIONS

The distribution network can be subdivided into three circuits: "supply", "return" and "fresh air"
An example of *supply* circuit calculation is shown by Figure 3.

The system is supposed to be sized in such a way to get a sufficient total pressure in the "least favourable" room (the one with the highest pressure drops from the fan exhaust). According to the VAV box manufacturer, this minimum pressure is around 250 Pa. The calculation, which is presented by Figure 4, shows that, with such a value, the pressure is acceptable in all rooms connected to this AHU. The same calculation shows that the connection between block B and block C is responsible for a very important pressure drop (125 Pa), which requires a pressure of 542 Pa at the fan exhaust. The same observation holds for the *return* circuit: the block B-block C connection is characterized by a high pressure drop (see Figure 4).

The calculation performed on the *fresh air* circuit (Figure 5), shows that this circuit works with a high pressure drop (187 Pa), one half of it being "consumed" by the silencer.

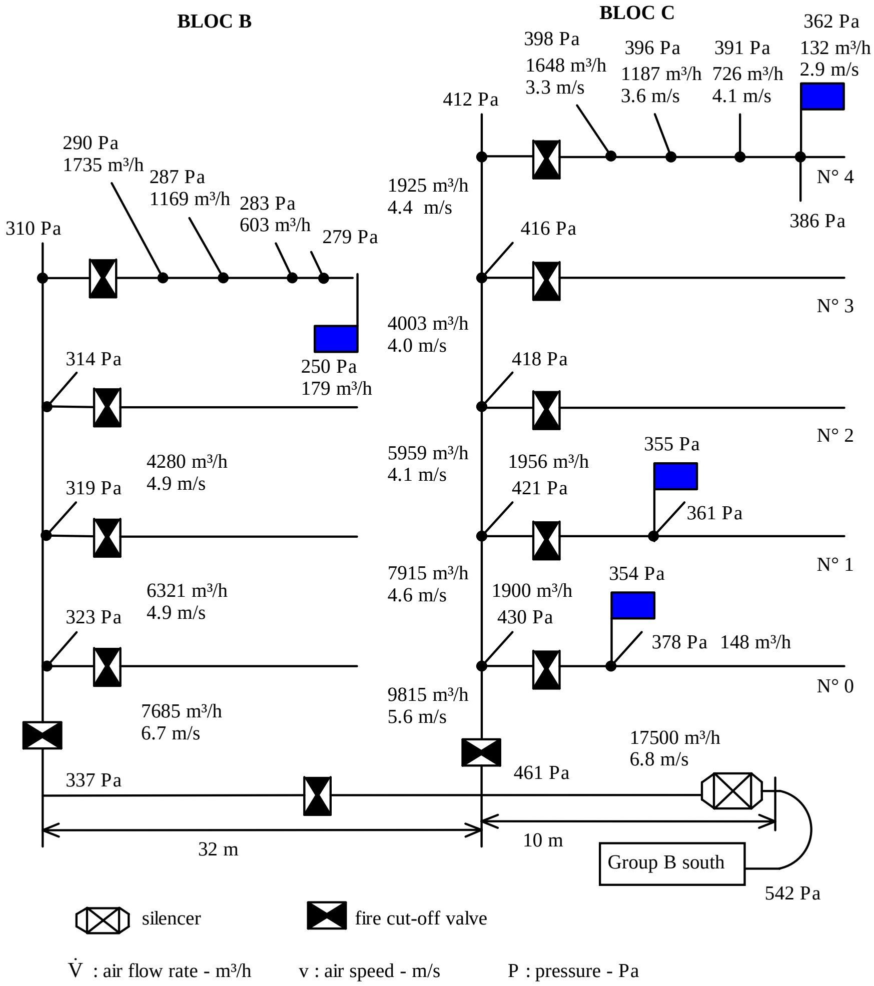

Figure 3: Calculation of over-pressures in the supply circuit

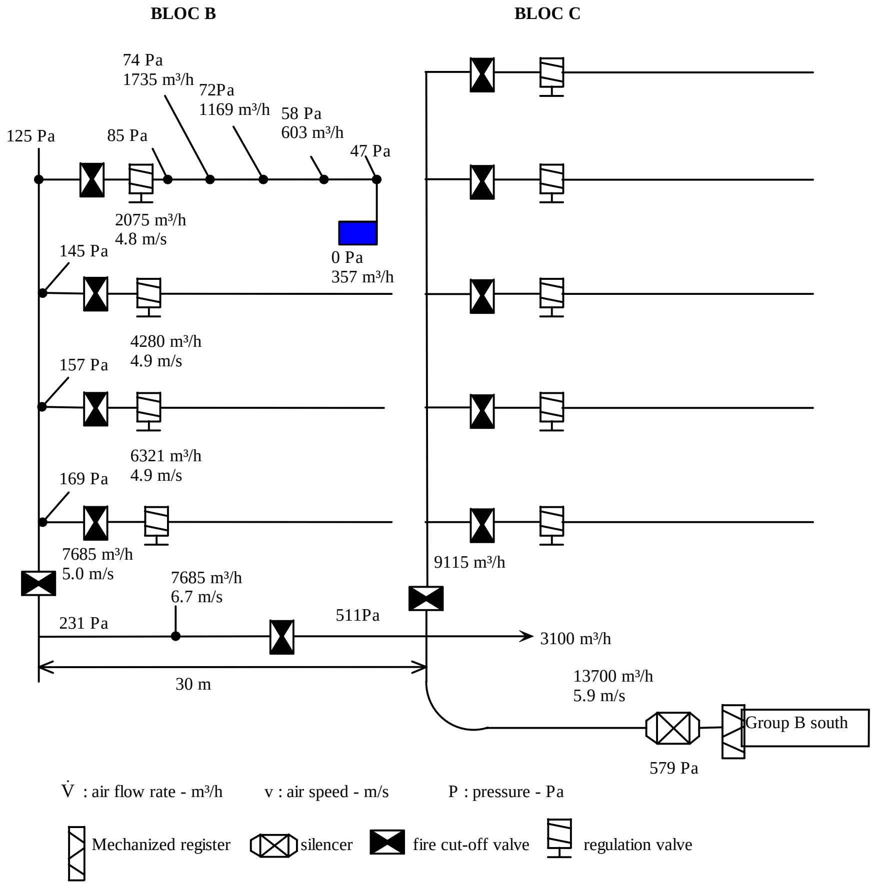

Figure 4: Calculation of under-pressures in the return circuit

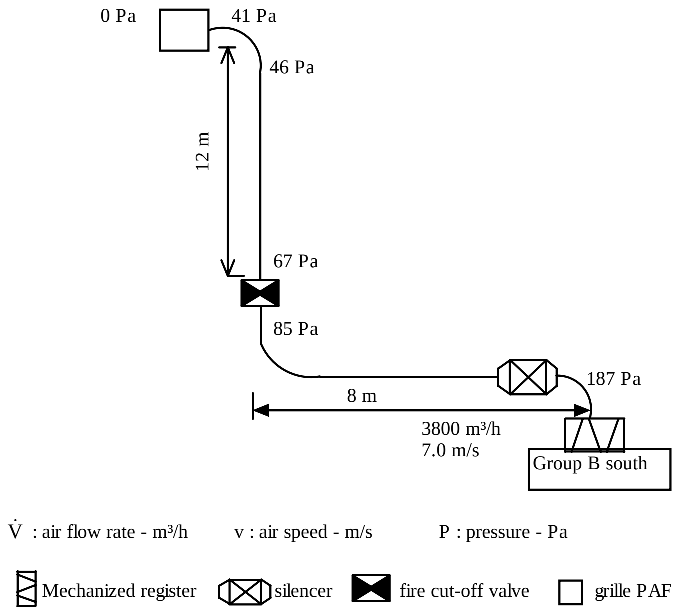

Figure 5: Calculation of under-pressures in the fresh air circuit

ANALYSIS OF THE CALCULATION NOTE PROVIDED BY THE INSTALLER

In the present case, the calculations performed by the installer (Figures 6 to 8) only concern to the most disadvantaged rooms with a “security orientated” overestimation of the pressure drops of the different components as the silencers, grilles and fire protection dampers. The overestimation factor is of around 30%.

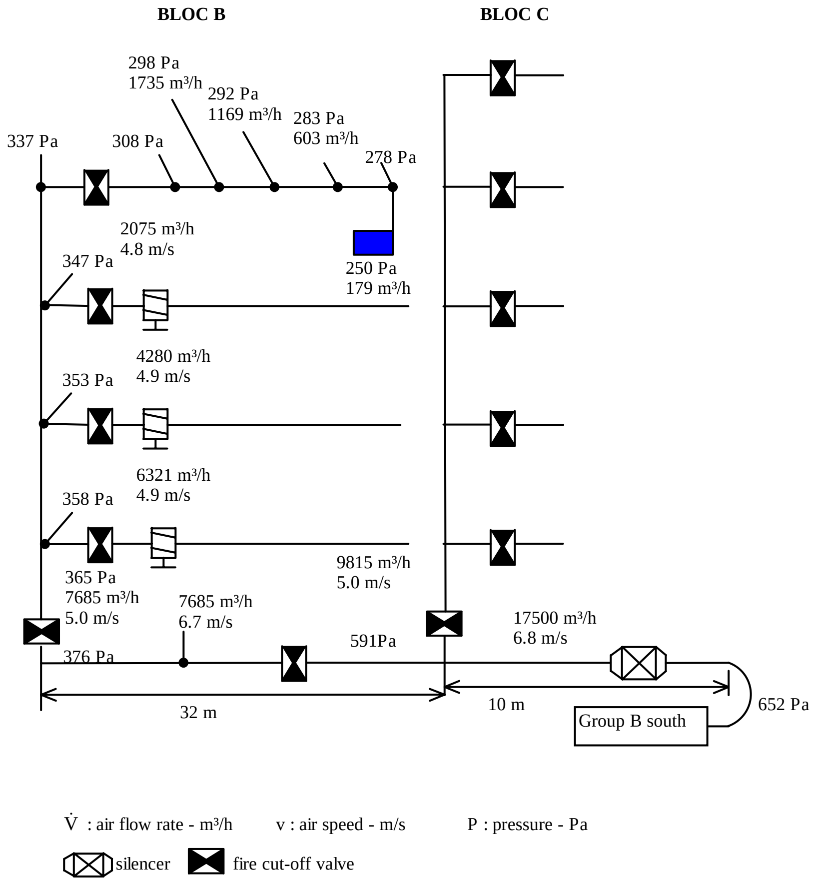

Figure 6: Calculation of over-pressures in the supply circuit, according to the installer

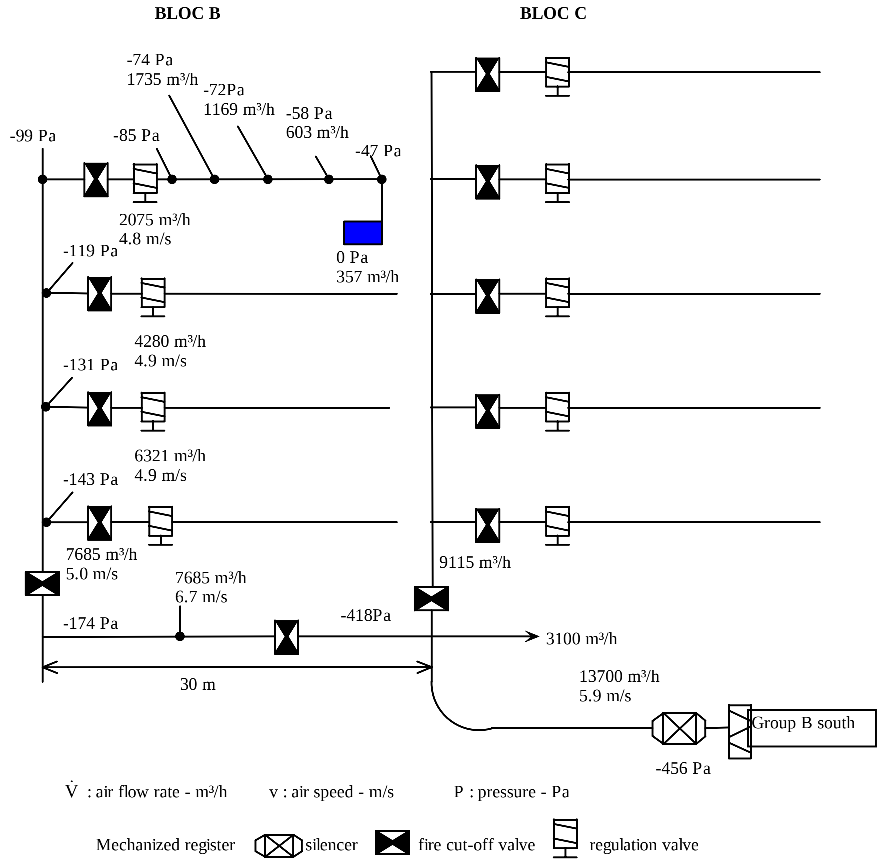

Figure 7: Calculation of under-pressures in the return circuit, according to the installer

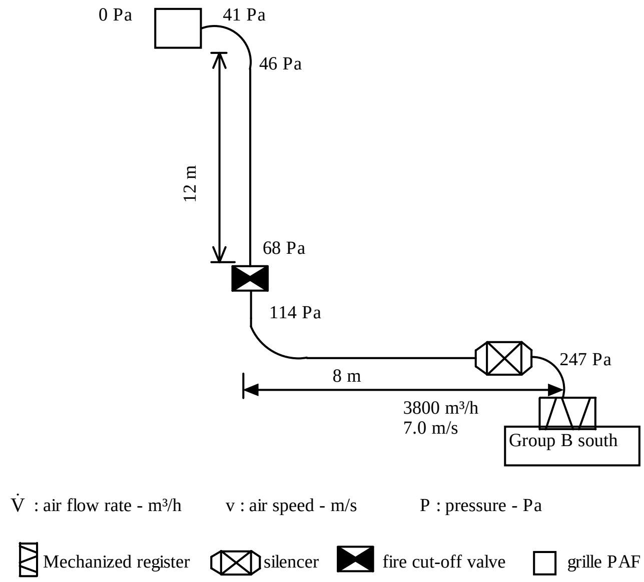

Figure 8: Calculation of under-pressures in the fresh air circuit, according to the installer

TESTING AND BALANCING OF THE SYSTEM

The *supply* circuit does not require any TAB: the VAV boxes do the job.
TAB dampers are located in the *return* circuit but do not seem having been used.
One consequence of this lack of TAB is the existence of significant pressure differences among the rooms, with a risk of cross-contamination and a lack of fresh air in some rooms.

FUNCTIONAL PERFORMANCE TESTS

Pressures have to be measured at a maximum of points of the schema. Existing sensors should not be trusted without re-calibration. Movable reference sensors with separate data logger have to be used as much as possible.
The definition of the two main airflow rates (fresh air and supply air) on the basis of the pressure differences $\Delta p1$ and $\Delta p4$ assumes a preliminary identification of the corresponding resistances (R1 and R4).
This means that the air flow rates have to be measured in an other way.
Two approaches can be used:

- Direct measurements of velocity profiles inside the ducts: not very accurate in this case because there is a lack of straight pieces of ducts in the technical room . An example is shown in Figure 9: none of the different measuring sections is very satisfactory and, consequently, none of the measuring results are very reliable...

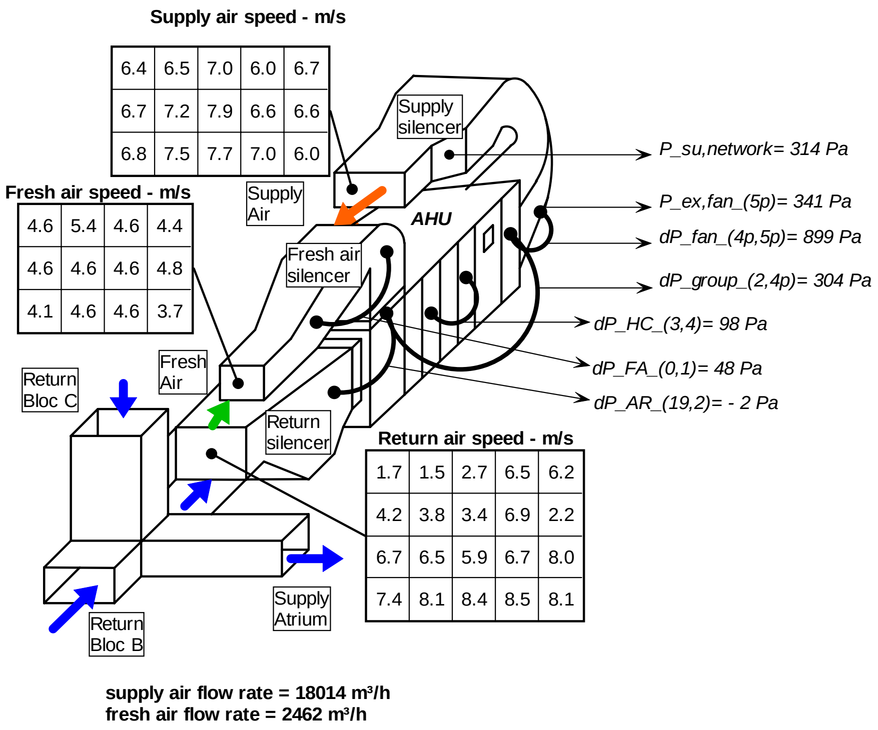

Figure 9: Estimation of airflow rates from air velocities measurements in the ducts

- Measurements of pressure differences, rotation speed and electrical power for supply and exhaust fans are made.

This second approach makes use of the characteristics provided by the fan manufacturer. It is safe if the fan is carefully identified (a checking of impeller diameter and of blades number is helpful to remove any doubt) and if its characteristics are “well” used:

In the present case, the *supply* fan has backward oriented blades; this gives enough slope to the $\Delta p = f(V)$ characteristic and therefore an accurate enough definition of V as function of Δp, for a given rotation speed.

At maximum flow rate (Figure 10) , the measured total pressures are lower than the calculated ones: supply pressure could be reduced in this case.
At minimum flow rate (Figure 11), pressure drops are very small.
As a consequence, it should be possible to reduce the supply pressure

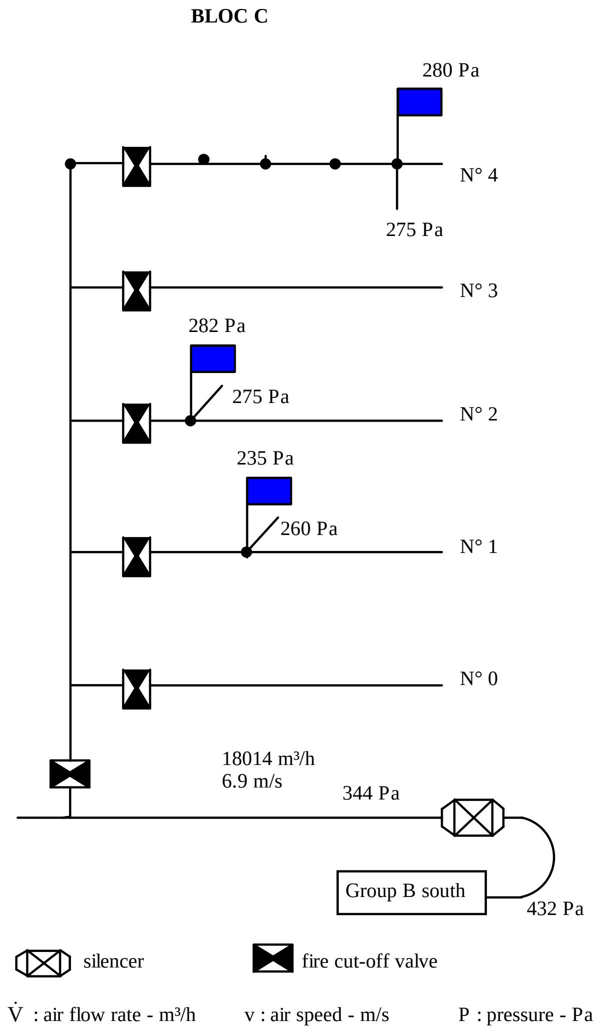

Figure 10 : Measurements in “B-C” AHU at maximum flow rate

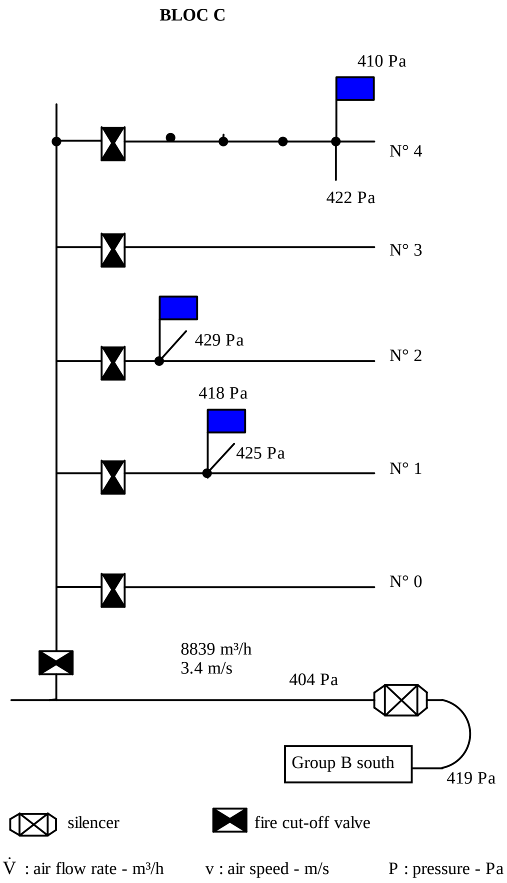

Figure 11: "B-C" AHU measurements at minimum flow rate

CONCLUSIONS

The following conclusions can be extracted from this re-commissioning experience:

In this particular case, it was found that :

- Most of the thermostats of the VAV boxes were not correctly connected or tuned;

- The supply air pressure was not correctly controlled (because of many alterations in the system : pressure signal conversion, set point, frequency range, etc);
- The supply air temperature was poorly controlled (due to a wrong definition of the outside air temperatures);
- The fresh air flow rate was also poorly controlled;
- The initial commissioning didn't fulfil the minimal TAB requirements;
- All faults found in the re-commissioning process had been easy to correct;

HVAC commissioning may appear as an end-less story, but it may open the way to a lot of improvements, if taking the best profit of all calculations and measurements available. A better dialog with manufacturers and installers would make the commissioning much more efficient…

The designer office should participate more effectively in the commissioning procedure. He should impose strict rules about the localization and the characteristics of all sensors, about the data logging, about the storage of the measuring results and about the way this information is to be processed by the BEMS.

The whole commissioning story should be recorded in the "as built" documents and these documents should be continuously up-dated.

With the help of the BEMS (and after having it carefully commissioned) most of the commissioning procedure might be automated…

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